Unit 2: Waves and Electricity

2.3 Waves and Particle Nature of Light

This topic covers the properties of different types of wave, including standing waves. Refraction, polarisation and diffraction are also included and the wave/particle nature of light. This topic should be studied by exploring the applications of waves, for example applications in medical physics or music.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

<table>
<tr><td>33</td><td>understand the terms amplitude, frequency, period, speed and wavelength</td></tr>
<tr><td></td><td>

Amplitude: the magnitude of maximum displacement reached by an oscillation in the wave (from its equilibrium position)

Frequency: the number of complete wave cycles per second

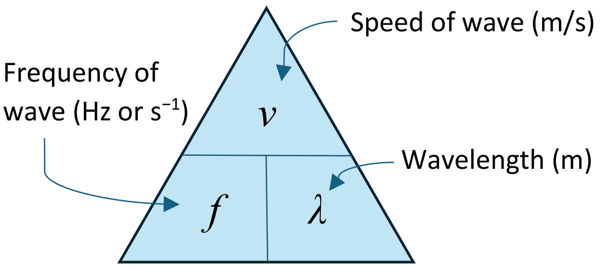
$$\text{Frequency (Hz)} = \frac{1}{\text{time period (s)}} \qquad f = \frac{1}{T}$$

T = time taken for one complete oscillation (time between two peaks on a S-T graph)

Wave speed: the rate at which a wave travels through a medium, indicating how quickly the wave's energy is transferred

Wavelength: the distance between two consecutive points in a wave that are in the same phase, like two crests or two troughs

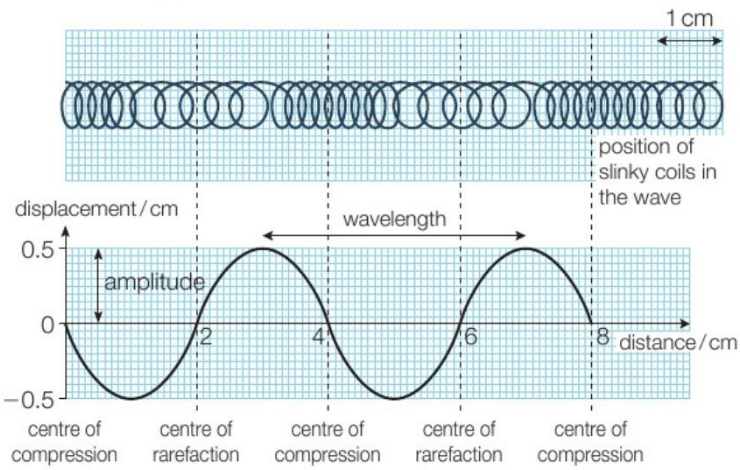
</td></tr>
<tr><td>34</td><td>be able to use the wave equation $v = f\lambda$</td></tr>
<tr><td></td><td>



The wave equation tells us that for a wave of constant speed:

- As the wavelength **increases,** the frequency **decreases**
- As the wavelength **decreases,** the frequency **increases**

</td></tr>
<tr><td>35</td><td>be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules</td></tr>
<tr><td></td><td>



Longitudinal waves are waves in which oscillations (vibrations) of particles occur parallel to the direction of energy transfer (or) propagation of wave

Longitudinal waves show areas of high pressure (compression) and low pressure (rarefaction)

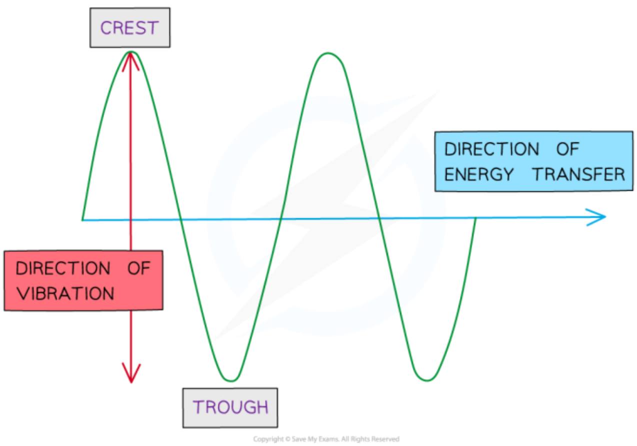
Longitudinal waves cannot be polarised

Examples: Sound waves
P-waves

From this graph we can see that at the centre of a compression or a rarefaction, the *displacement of molecules is zero*

</td></tr>
</table>

36 be able to describe transverse waves



Transverse waves are waves in which oscillations(vibrations) of particles occur perpendicular to the direction of energy transfer (or) propagation of wave

Transverse waves show areas of crest and trough

Transverse waves can be polarized

Examples:

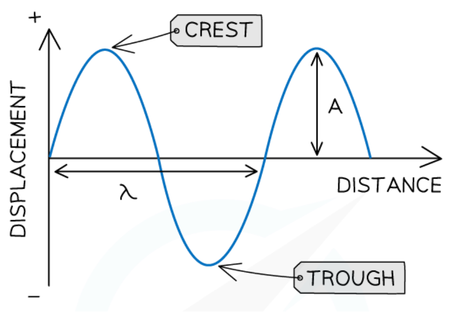
- Electromagnetic waves
- Waves on rope or slinky

37 be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves

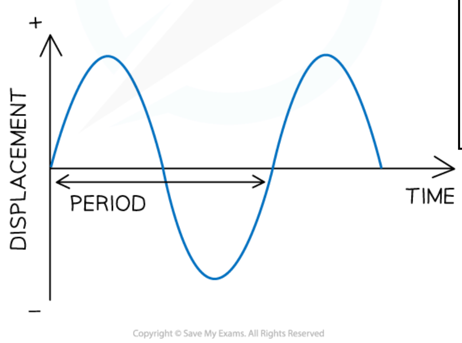
Amplitude & Wavelength can be found from Displacement-Distance graph

Two Main Graphs of Transverse Waves

Displacement-Distance Graph



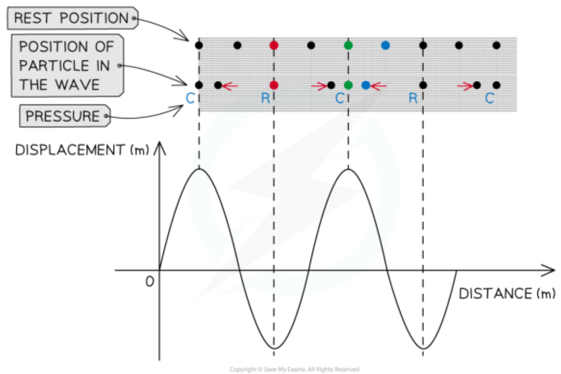
Displacement-Time Graph



Wavelength cannot be determined from Displacement-Time graph

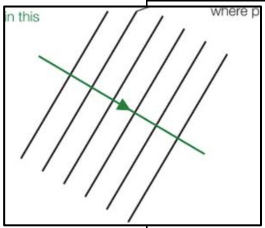
Graph of Longitudinal Waves

Displacement-Distance Graph



38 **CORE PRACTICAL 4: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone**

39	know and understand what is meant by *wavefront, coherence, path difference, superposition, interference* and *phase*



Wavefront: the line connecting all points on a wave that are in the same phase position

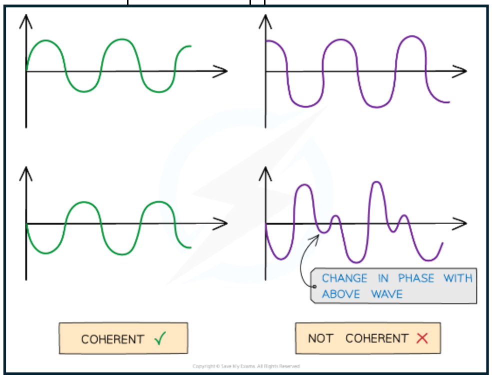
What is a phase anyways?

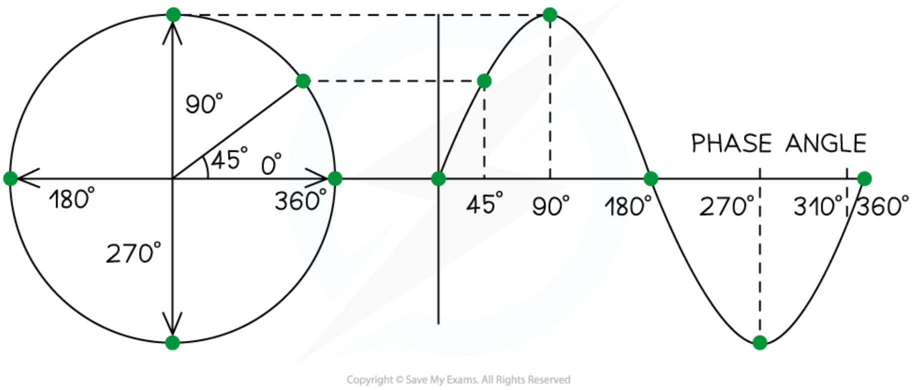
Waves repeat a pattern over time or space as they oscillate repeatedly in *cycles*

To define phase, you need a reference point within that cycle which will be the wave's starting point in our definition

Phase is represented as an angle, where a full cycle is 360 degrees (or 2п radians)

For example, at the start of a wave cycle, the phase is 0 degrees (or 0 radians), at the halfway point it's 180 degrees (or п radians), and at the end it's 360 degrees (or 2п radians)





Phase Difference:

When comparing *two waves*, the phase difference tells you how much one wave is ahead of or behind the other

- If two waves have the same phase (zero phase difference), their peaks and troughs align
- If they are out of phase, their peaks and troughs don't align, which can affect the overall wave

Coherence: waves which have the <u>*same frequency*</u> *and a* <u>*constant phase relationship*</u>
(Coherent waves are needed to form a stable standing wave)

Example: Laser light is a coherent light source as it is monochromatic and has a constant phase difference

Path difference: the difference in distance travelled by two waves from their sources to the point where they meet

Superposition: the overall displacement when two or more waves overlap which is the vector sum of the displacements caused by each individual wave

Interference: the superposition outcome when two or more waves overlap and combine to form a resultant wave

This combination can either increase or decrease the amplitude of the original waves, resulting in constructive or destructive interference, respectively

Interference is *only observable when produced by a coherent source!*

40	be able to use the relationship between *phase difference* and *path difference*

Constructive and Destructive Interference

- When two waves meet and interfere, whether a particular point undergoes constructive or destructive interference <u>depends on the path difference</u> which in turn depends on the phase difference
- Let’s revisit the definitions for phase difference and path difference:
- Phase difference is the angle between the wave cycles when those two waves meet
- Path difference is the difference in distance travelled by two waves from their

sources to the point where they meet
- Path difference and phase difference are directly related

In general,
- The condition for *constructive interference* is a path difference of $n\lambda$
- The condition for destructive interference is a path difference of $(n+1/2)\lambda$ where n is an integer
- A path difference equal to $n\lambda$ exactly will have a phase difference of $2n\pi$ exactly and will be in phase, producing constructive interference
- A path difference equal to $(n+1/2)\lambda$ exactly will have a phase difference of $(2n+1)\pi$ exactly and will be in anti-phase, producing destructive interference

Remember! For all this to occur, the waves need to be coherent

41 know what is meant by a *standing/stationary* wave and understand how such a wave is formed, know how to identify nodes and antinodes

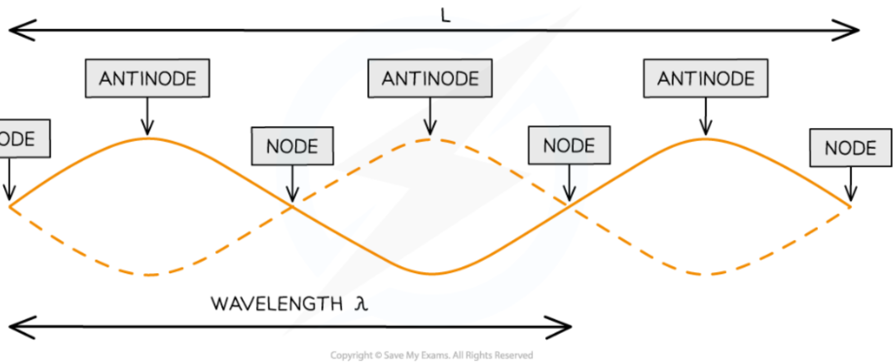
Standing Wave (a.k.a Stationary Wave)
- They are waves which has oscillations in a fixed space, with regions of *significant oscillation (anti-nodes)* and *regions with zero oscillation (nodes),* which remain in the same locations at all times
- Standing waves are produced by the superposition of two waves of the *same frequency and amplitude* travelling with the same speed in **opposite directions** (with a constant phase relationship)
- There is **no net energy transfer** along a stationary/ standing wave unlike progressive waves (The waves combine in a way that cancels out the forward and backward motion, resulting in a fixed pattern that makes oscillate in place, rather than traveling through space)

Nodes are regions on a stationary wave where the amplitude of oscillation is at its minimum/ zero

Anti-nodes are regions on a stationary wave where the amplitude of oscillation is at its maximum

The nodes and antinodes **do not** move along the string

Nodes *are fixed* and **antinodes** *only move in the vertical direction*



How stringed instruments such as the violin work is that the vibrations caused by stationary waves on a stretched string produce sound

- This can be seen in stringed instruments (such as the guitar), microwaves and air columns (such as in trumpets/ clarinets)

42 be able to use the equation for the speed of a transverse wave on a string $v = \sqrt{\frac{T}{\mu}}$

This is the equation for the speed of a transverse wave along a string:

$$v = \sqrt{\frac{T}{\mu}}$$

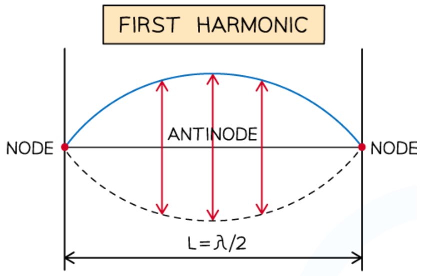
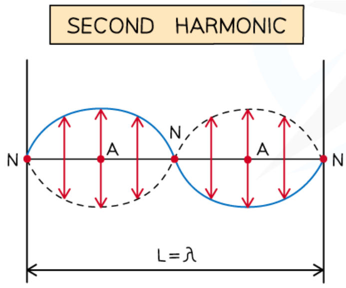
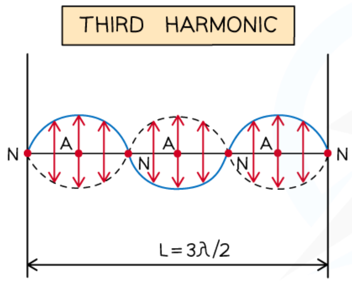
Where T = tension in the string (N), μ is the mass per unit length of the string (kg/m)

(μ can be calculated by dividing mass of string by length of string)

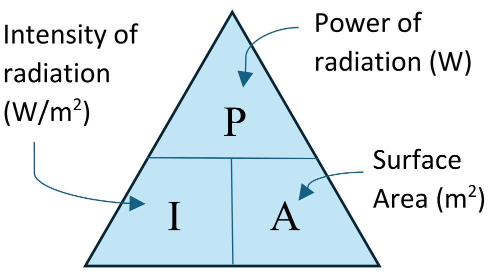
At the fundamental frequency, f_0, of a stationary wave of length L, wavelength λ = 2L

Hence, the speed of the stationary wave becomes: $v = f\lambda = f(2L)$

Combining this equation with that from above,
we get the equation for the fundamental frequency (first harmonic): $f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$

Mode	**Wavelength λ**	**Frequency = v / λ**
Fundamental 	WAVELENGTH λ $\lambda = 2L$	FREQUENCY = $\frac{v}{\lambda}$ $f = \frac{v}{2L}$
1st Overtone 	$\lambda = L$	$f = \frac{v}{L}$
2nd Overtone 	$\lambda = \frac{2L}{3}$	$f = \frac{3v}{2L}$

43	**CORE PRACTICAL 5: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire**
44	be able to use the equation for the intensity of radiation $I = \frac{P}{A}$

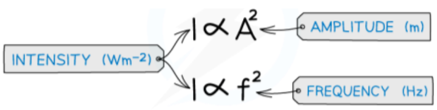


Progressive waves transfer **energy**

The amount of energy passing through a unit area per unit time is the **intensity** of the wave

The **area** the wave passes through is **perpendicular** to the direction of its **velocity**

The **intensity** of a progressive wave is also proportional to its **amplitude squared** and **frequency squared**

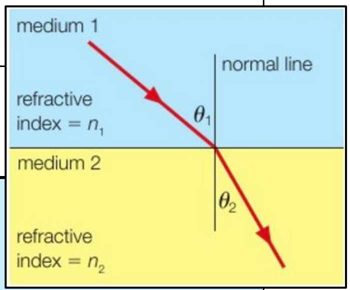


45	know and understand that at the interface between medium 1 and medium 2 $n_1 \sin\theta_1 = n_2 \sin\theta_2$ where refractive index is $n = \frac{c}{v}$

Refraction & Refractive Index

- Refraction is the change in speed of wave when a wave moves from one medium to another, during which there is a corresponding change in direction of wave, governed by Snell's law
- At the boundary between two different media, the rays of light undergo a change in direction due to a change in speed (which in turn causes a change in wavelength
- Entering a **more dense** medium **slows** light down, bending it **towards** the normal
- Entering a **less** dense medium **speeds** light up, bending it **away** from the normal
- When passing **along the normal** (perpendicular to boundary) the light does not change direction but its speed does still change
- A measure of the amount of refractive caused by different materials is called the **refractive index**
- There are two formulas for calculating refractive index 'n'

$n = \frac{c}{v}$	Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$



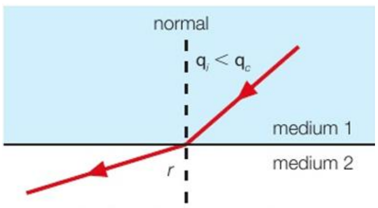
Always assume that $n_{air} = 1$
And that the refractive index you calculated should never be less than 1

be able to calculate critical angle using:

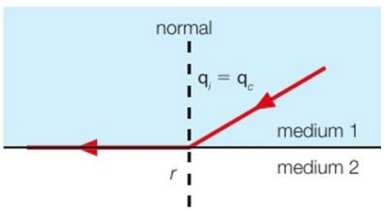
$$\sin C = \frac{1}{n}$$

Critical Angle

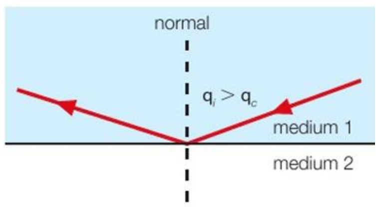
- As the angle of incidence at the boundary between a more dense and a less dense medium is increased, the angle of refraction also increases until it gets to 90°
- When the angle of refraction is exactly 90° the light is refracted along the boundary (if the boundary is straight)
- At this point, the angle of incidence is known as the critical angle *C*
- This can only occur when light passes from a more dense to a less dense material



i is less than critical angle

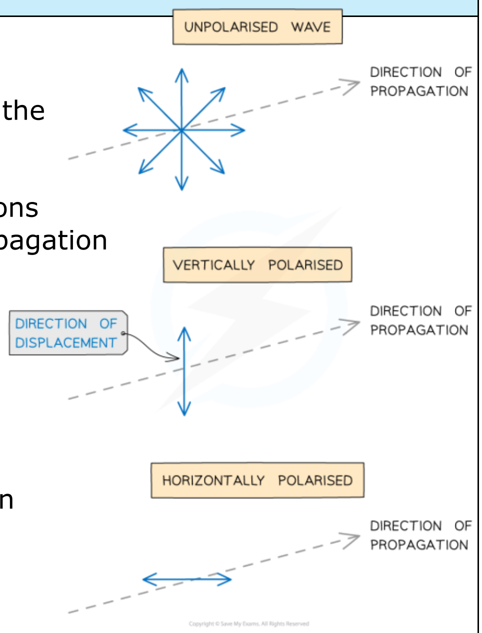


i equals critical angle



angle of incidence greater than critical angle

Note that when refraction occurs, (amplitude, speed, wavelength changes but) the frequency does not change as the frequency only depends on the source of the wave

47	be able to predict whether total internal reflection will occur at an interface
	Two conditions are needed for **Total Internal Reflection** to occur: 1. Light must be going from MORE DENSE to LESS DENSE medium ($n_1 < n_2$) 2. Angle of incidence > critical angle ($\angle i > \angle c$)
48	understand how to measure the refractive index of a solid material
	How to measure the refractive index of a solid material 1. Place a glass block on a sheet of paper and trace around it using a pencil 2. Switch on the ray box and direct a beam of light at the side face of the block 3. Mark on the paper with a small 'x': • A point on the ray close to the ray box • The point where the ray enters the block • The point where the ray exits the block • A point on the exit light ray which is a distance of about 5 cm away from block 4. Draw a dashed line normal (at right angles) to the outline of the block 5. Remove the block and join the points marked 'x' with a ruler 6. Place the block again and vary the angle of incidence by placing the ray box at different positions 7. Repeat the process for several different angle of incidence
49	understand what is meant by plane polarisation
	Plane Polarisation  - **Transverse waves**, such as light and other electromagnetic waves, oscillate perpendicular to the direction the motion (and energy transfer) - In **unpolarised** transverse waves, the electric and magnetic fields oscillate in all possible directions perpendicular to the direction of wave travel/ propagation - **Polarisation** is the process of restricting these oscillations of the wave's electric and magnetic fields to a single fixed plane perpendicular to the direction of wave travel/ propagation - The plane containing the direction of propagation and the electric (or magnetic) field is called the **plane of polarization** - Only transverse waves can be polarized because in longitudinal waves, particles oscillate in the same direction as the direction of motion of the wave <u>Difference between unpolarized and polarized light</u> - Unpolarized light has oscillations/vibrations in all planes/directions - Plane polarized light only has oscillations/vibrations in one plane/direction which is perpendicular to the direction of wave travel - A few ways of polarization: 1. Polarising filters/ Polaroid filters 2. Polarisation by reflection and refraction (from a non-metallic surface) 3. Polarization by chemical solutions (less common) <u>How to demonstrate that light is unpolarized</u> - Direct the light through a polarizing filter - If there is no change in intensity as the filter is rotated, then it is unpolarized - If the intensity of light changes, then the light is polarised

50 | understand what is meant by diffraction and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle

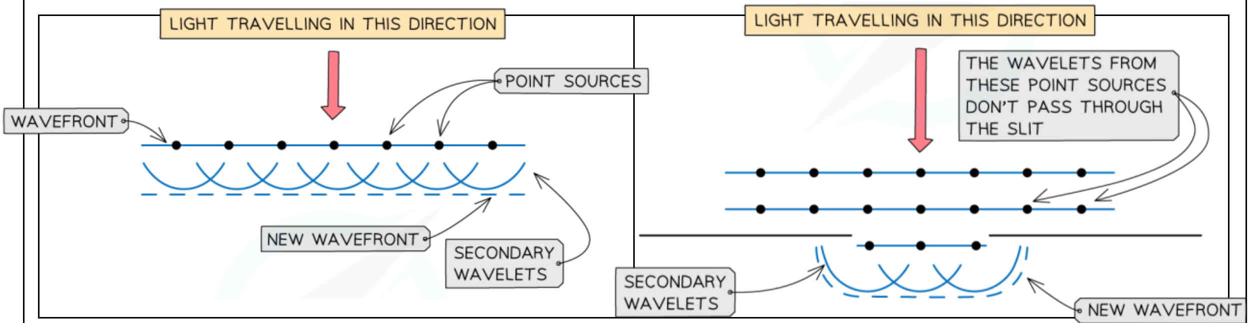
Diffraction

- is the **spreading out of wave energy when they pass an obstruction** (mainly diffraction through a gap (slit) and diffraction around an object)
- Wavelength does not change when diffraction occurs
- The only property that changes is the ***amplitude*** (because some energy is dissipated when diffracting through a gap)

<u>Factors affecting diffraction</u>

- Diffraction mostly occurs when gap size is roughly the same or smaller than the wavelength of the wave
- When the gap is much larger than the wavelength, the waves no longer spread out

<u>**Huygen's Principle**</u>



- Huygen's principle is used to predict the future movement of waves when a wave meets a slit or an obstacle
- Huygen's model states that *every point on a* ***wavefront*** *can be considered to be a point source of secondary waves* (wavelets)
- The superposition of these waveletsare connected to form a resultant wave which will become the new wavefront

51 | be able to use $n\lambda = d\sin\theta$ for a diffraction grating

The Diffraction Grating Equation

- A **diffraction grating** is a plate on which there is a large number of parallel, identical, equally-spaced slits with a fixed spacing
- When **monochromatic light** (light with only one wavelength) is incident on a diffraction grating, a pattern of narrow bright fringes is produced on a screen
- This is due to light diffracting through the narrow slits in the grating and then the diffracted light interfering with each other
- Where the waves interfere constructively, they create bright spots, and where they interefere destructively, they create dark spots
- The angles at which the maxima of intensity (constructive interference) are produced can be deduced by the diffraction grating equation:

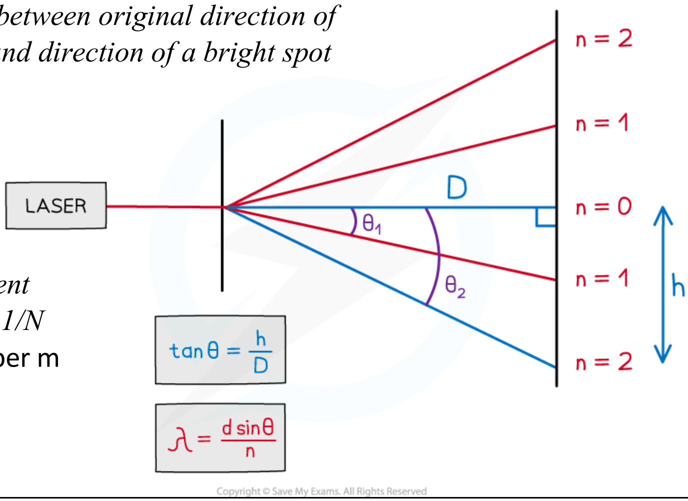
Order of maxima, n = 0,1,2,...
(n must be an integer)
(if decimal, round down)

Angle between original direction of wave and direction of a bright spot

$$n\lambda = d\sin\theta$$

Wavelength of source

Spacing between adjacent slits on the grating d = 1/N
where N = no. of lines per m



The maximum angle to see orders of maxima is when the beam is at right angles to the diffraction grating

The highest order of maxima visible is therefore calculated by the equation: $n = \frac{d}{\lambda}$

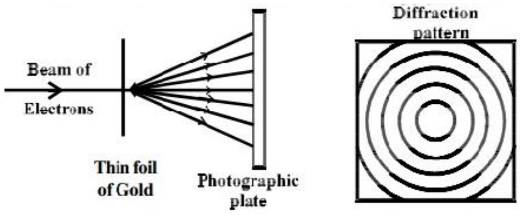
52 **CORE PRACTICAL 6: Determine the wavelength of light from a laser or other light source using a diffraction grating**

53 understand how diffraction experiments provide evidence for the wave nature of electrons

For diffraction to occur, electrons must be focused through a gap similar to their size, an atomic lattice is ideal for this

Wave nature of electrons

- In an electron diffraction experiment, a beam of electrons is accelerated in an electron gun and then directed at a thin crystalline material, such as a graphite film
- The electrons, which were previously thought to be only particles, are diffracted by the crystal's atomic lattice and produce a circular pattern of concentric rings on a **fluorescent screen** made from phosphor
- Diffraction and interference are characteristic wave behaviours
- If the electrons acted as particles, a pattern would not be observed, instead, the particles would be distributed uniformly across the screen



Diffraction of electron beam by thin foil of gold (G.P. Thomson experiment)

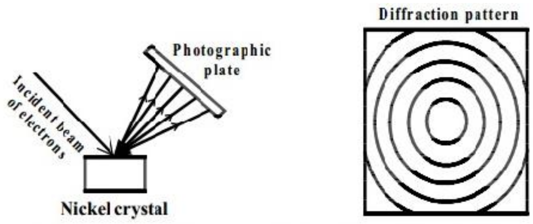


Fig. Electron diffraction experiment by Davisson and Germer

54 be able to use the de Broglie equation

$\lambda = \frac{h}{p} = \frac{h}{mv}$

De Broglie Equation

- Using ideas based upon the quantum theory and Einstein's theory of relativity, De Broglie theorised that not only do EM waves sometimes behave as particles, but that very small, fast moving particles like electrons could also behave as waves
- De Broglie proposed an equation that said the wavelength of the electron is inversely proportional to the momentum they have when considered as particles
- The De Broglie wavelength of electrons is similar to the spacing of gaps between atoms

$E = hf$ and $E = mc^2$

$$hf = mc^2$$

$$\frac{hc}{\lambda} = mc^2$$

$$\frac{h}{\lambda} = mc$$

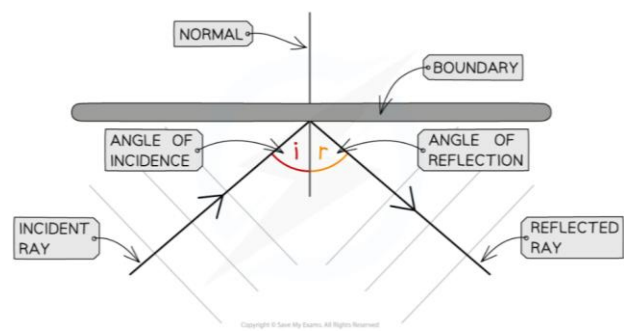
$$\frac{h}{mv} = \lambda$$

55 understand that waves can be transmitted and reflected at an interface between media

When waves are incident on the interface between two different media, they are either transmitted or reflected

- When the media have similar densities (refractive indexes), the energy of the wave is mostly transmitted
- When the media have different densities (refractive indexes), the energy of the wave is mostly reflected

Reflection	**Transmission**

		 Transmission can involve refraction but transmission is when the wave passes through the media and emerges out of it
56	understand how a pulse-echo technique can provide information about the position of an object and how the amount of information obtained may be limited by the wavelength of the radiation or by the duration of pulses	

For sonar explorations, the <u>*distance*</u> the wave travels is <u>*twice the depth*</u> of the ocean so it needs to be halved before making any calculations

Pulse-echo Technique

- An ultrasound detector is made up of a *transducer* that produces and detects a beam of ultrasound waves into the object
- The ultrasound waves are reflected back to the transducer by different *boundaries* between objects in the path of the beam
- Using the speed of sound and the time of each echo's return, the detector calculates the distance from the transducer to the boundary

Resolution

- Is the amount of detail which can be captured which depends on the *wavelength*
- **Shorter** wavelengths have **smaller (better)** resolution
- **More** detail can be seen since they diffract (spread out) less
- More energy is needed as short wavelength waves have higher frequency
- Ideally, wavelength is chosen to be similar in size to object that is being resolved
- This combination of **short pulses** with relatively **large spaces** between them produces the **clearest** images

57	understand how the behaviour of electromagnetic radiation can be described in terms of a wave model and a photon model, and how these models developed over time

Wave-Particle Duality

Electromagnetic radiation such as light can be described using both a **wave model** and a **photon model**

★ The **wave model** explains phenomena like interference and diffraction by Young's double slit experiment

★ The **photon model** is useful for understanding interactions with matter, like the photoelectric effect

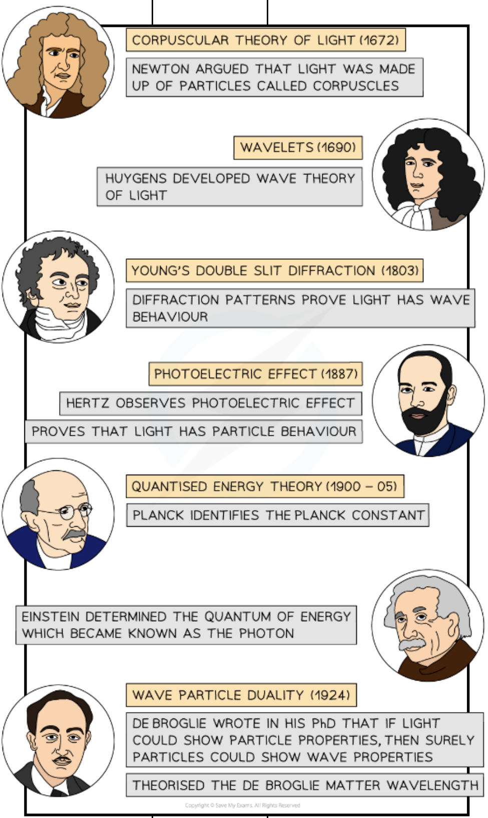
<u>**Photon model**</u>

Einstein proposed that light can be described as a quantum of energy that behave as particles, called photons

- The photon model describes electromagnetic radiation as a stream of discrete energy packets called photons
- Each photon carries a specific amount of energy, related to its frequency ($E = hf$)
- This model is useful for explaining phenomena where electromagnetic radiation interacts with matter, like the photoelectric effect.
- In the photoelectric effect, each electron can absorb a single photon, causing them to be emitted from a material if the photon's energy (or the frequency of its light) is above a certain threshold (energy/ frequency)

In the photon model, **intensity** of light does NOT affect the energy of the photon or the electron released

The wave theory of light does NOT support the idea of a threshold frequency



Wave model

The wave theory suggests any frequency of light can give rise to photoelectric emission if the exposure time is long enough

- This is because the wave theory suggests the energy absorbed by each electron will increase gradually with each wave
- Furthermore, the kinetic energy of the emitted electron should increase with radiation intensity
- In the wave model, the energy is built up over time and transferred to the electron slowly so electrons would not be released immediately
- In the wave model, if the frequency of the incident light is above the threshold frequency and the **intensity** of the light is increased, **more photoelectrons are emitted per second**
- However, this is not what is observed in the photoelectric effect

The wave theory of light suggests...	This is wrong because...
Any frequency of light can give rise to photoelectric emission if the exposure time is long enough	Photoelectrons will be released immediately if the frequency is above the threshold for that metal
The energy absorbed by each electron will increase gradually with each wave	Energy is absorbed instantaneously – photoelectrons are either emitted or not emitted after exposure to light
The kinetic energy of the emitted electrons should increase with radiation intensity	If the intensity of the light is increased, more photoelectrons are emitted per second

58 be able to use the equation $E = hf$, that relates the photon energy to the wave frequency

Energy of a Photon

- The energy of a photon is given by the equation **E = hf**
  where E is the energy, h is Planck's constant, and f is the frequency of the photon
- Alternatively, it can be expressed as **E = hc/λ**
  where c is the speed of light and λ is the wavelength
- This means "Energy of a photon is directly proportional to the frequency of a wave"
- Higher photon energy means higher frequency of incident wave

59 understand that the absorption of a photon can result in the emission of a photoelectron

The Photoelectric Effect

- is the phenomena in which electrons (photoelectrons) are emitted from the surface of a metal upon the absorption of photons (electromagnetic radiation)
- The photoelectric effect provides evidence that light is quantized (i.e. light is carried in discrete packets)
- Photoelectrons are only emitted from a given metal surface if the frequency of the incident radiation is above a particular value (called the threshold frequency)
- This is because: as E = hf, higher frequency of incident radiation means higher photon energy
- This means the energy of photon can be greater than the work function which is the minimum amount of energy needed for electron emission from surface
- Each photon can only interact with (be absorbed by) one electron

Intensity affects the number of photons incident per second

Intensity affects the number of electrons released per second (if energy of photon is greater than the work function)

But Intensity does NOT affect the energy of the photons or the electrons released so higher intensity does not necessarily mean emission of electrons if the energy absorbed by electron is still less than the work function

60 understand the terms 'threshold frequency' and 'work function' and be able to use the equation

$$hf = \phi + \tfrac{1}{2} mv_{max}^2$$

Energy of incident photon (E) = Planck's constant (h) x *frequency of incident radiation (f)*

Maximum KE of the photoelectrons (J)

$$hf = \phi + \tfrac{1}{2} mv_{max}^2$$

Work function = minimum energy needed by an electron to escape from the surface of a metal (J)

This equation demonstrates that:

- If the photoelectrons do not have a high enough frequency and energy to overcome the work function(ϕ) then no electrons will be emitted
- If $hf_0 = \phi$, where f_0 = threshold frequency, photoelectric emission only just occurs
- KE_{max} depends only on the **frequency** of the incident photon, **not on the intensity** of the radiation
- The majority of photoelectrons will have KE < KE_{max}
- A single electron can only absorb one photon

61 be able to use the electronvolt (eV) to express small energies

$1eV = 1.6 \times 10^{-19}$ J

Electronvolt is the energy gained by an electron travelling through a potential difference of 1 volt

E = QV = charge of 1 electron x 1 voltage = 1.6×10^{-19}C x 1V = 1.6×10^{-19}J = 1eV

62 understand how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation

Observations of the gold-leaf experiment

The photoelectric effect provides strong evidence for the particle nature of electromagnetic radiation because it demonstrates that light can behave as discrete packets of energy, called photons, rather than just a continuous wave

The key observations that contradict the wave theory and support the particle theory include: the existence of a threshold frequency, the independence of electron kinetic energy on light intensity, and the direct relationship between light intensity and the number of emitted electrons

	Threshold Frequency	**Independence of Electron Kinetic Energy on Light Intensity**	**Direct Relationship between Light Intensity and Number of Emitted Electrons**
Wave Theory Prediction	Wave theory predicted that if light of sufficient intensity, regardless of its frequency, is shone on a metal surface, it should eventually provide enough energy to emit electrons	According to the wave theory, increasing the intensity of light should increase the energy absorbed by the electrons, leading to higher kinetic energies for the emitted electrons	The wave theory doesn't provide a clear prediction about the relationship between light intensity and the number of emitted electrons

Experimental Observation	However, experiments showed that electrons are only emitted if the incident light has a frequency above a certain threshold. Light with a frequency below this threshold, even with great intensity does not cause any electron emission	Experiments showed that increasing the intensity of light above the threshold frequency only increases the number of emitted electrons, not their kinetic energy	Experiments consistently showed that increasing the intensity of light above the threshold frequency (by placing the UV light source closer to the metal plate) increases the number of electrons emitted
Photon Theory Explanation	The photon theory explains this by stating that light energy is quantized into discrete packets called photons. Each photon has an energy proportional to its frequency ($E = hf$). If the photon's energy (frequency) is below a certain value (work function), it doesn't have enough energy to emit an electron	The photon theory explains this by stating that each electron can absorb only one photon. Increasing the intensity increases the number of photons, thus more electrons are emitted, but the kinetic energy of each emitted electron depends only on the energy of the photon it absorbed i.e. depends only on the frequency of light source as $E = hf$	In the photon theory, increasing the intensity of light means increasing the number of photons incident per second. If each photon can cause one electron emission, then a higher intensity of light will lead to more electrons being emitted

Do note this summary of observations:

- Light travel as photons, with energy of a photon being directly proportional to its frequency as $E = hf$
- When a photon encounters an electron, it transfers all its energy to the electron (the photon ceases to exist)
- If the energy of the photon is equal to or greater than the work function of the metal, photoelectrons will be released instantaneously
- A single photon interacts with a single electron
- Kinetic energy of photoelectrons emitted depends on the frequency of light source, not its intensity
- Number of photoelectrons emitted per second depends on the intensity of light source, not its frequency as brighter (more intense) light source means more photons incident per second

63

understand atomic line spectra in terms of transitions between discrete energy levels and understand how to calculate the frequency of radiation that could be emitted or absorbed in a transition between energy levels

Atomic line spectra

Each element has a **unique line spectrum** due to its unique set of energy levels, acting like a fingerprint to identify the element

These spectra arise from electrons transitioning between energy levels within an atom, with each transition corresponding to a specific wavelength of light (which corresponds to the difference between these energy levels)

- Energy levels of electrons are **discrete** which means electrons can only exist at certain energy levels
- When atoms are given energy (through heating or electrical discharge), their electrons gain a discrete amount of energy and jump from lower to higher energy levels through **excitation**
- Excited electrons are unstable in that state and so they quickly return to lower energy levels, or their ground state, through **de-excitation**
- As the electrons drop back down, they **release energy** in the form of photons with a specific wavelength corresponding to the energy differences between the electron energy levels
- When these photons are passed through a prism or spectrometer, they create a line spectrum – a series of colored lines on a dark background.
- There are two types of Line Spectra:
- **Emission spectra:** Produced when excited atoms release energy as light
- **Absorption spectra:** Produced when atoms absorb light of specific wavelengths as their electrons jump to higher energy levels

What is a **line spectrum**?

A **line spectrum** (a.k.a an atomic line spectrum) is a unique pattern of discrete lines of colour of specific wavelengths (or frequencies) that are emitted or absorbed by an atom or molecule

Each line of the emission spectrum corresponds to a different energy level transition within the atom and so is unique to that element!

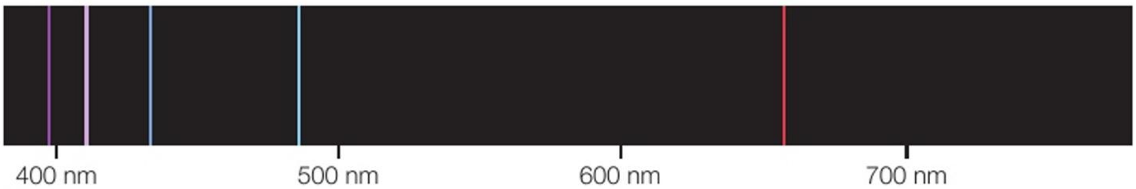


fig D Hydrogen emission line spectrum.

The energy required to move electrons from one energy level to another is given by the difference of energy between the two energy levels which corresponds to the energy of the absorbed or emitted photon

$$\Delta E = E_1 - E_2 = hf = \frac{hc}{\lambda}$$

Hence, the wavelength is inversely proportional to the energy level transition associated with the emitted photon